

**EXPLANATORY
NOTES**



GEOLOGY OF THE LAKE GILES 1:100 000 SHEET

by J. E. Greenfield

1:100 000 GEOLOGICAL SERIES



**GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
DEPARTMENT OF MINERALS AND ENERGY**



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

**GEOLOGY
OF THE LAKE GILES
1:100 000 SHEET**

**by
J. E. Greenfield**

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**Cover photograph:
View looking east towards Lake Barlee from a ridge of banded iron-formation (MGA 755200 6728000)**

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Geology of the Lake Giles 1:100 000 sheet

by

J. E. Greenfield

Abstract

The LAKE GILES 1:100 000 sheet comprises granite–greenstone terrain of the central Southern Cross Province of the Yilgarn Craton. The c. 3.0 Ga greenstone succession contains parts of five distinct greenstone belts — the Yerilgee, South Elvire, Mount Manning, Evanston, and Diemals belts — within the map area, separated by variously deformed monzogranite. The Yerilgee greenstone belt contains a thick sequence of high-Mg basalt intruded by gabbro sills, overlain by ultramafic rocks and banded iron-formation (BIF). High-Mg basalt and sedimentary rocks form the top of the sequence. The Mount Manning greenstone belt contains a thick sequence of basalt, overlain by chert and BIF, and a thin, distinctive unit of calc-silicate rock. High-Mg basalt, minor gabbro, and ultramafic rock overlie this unit. The South Elvire greenstone belt consists of two packages separated by the Evanston Shear Zone. The southern package contains calc-silicate rock overlain by tholeiitic basalt, ultramafic rock, BIF, and minor sedimentary rocks. The northern package contains BIF overlain by ultramafic rock and tholeiitic basalt. The Diemals greenstone belt consists of high-Mg basalt, tholeiitic basalt, BIF, and minor ultramafic and sedimentary rocks. The Evanston greenstone belt contains high-Mg basalt overlain by sedimentary and ultramafic rocks, intercalated with thin BIF lenses.

Four major deformation events are recognized. The first deformation (D_1), a layer-parallel foliation in metasedimentary rocks, has been folded by upright, northerly trending folds (D_2). The D_2 folds have been reorientated by westerly directed compression that is associated with significant lateral movement on ductile shear zones (D_3). Post-dating these structures are conjugate north-northeasterly trending dextral and east-southeasterly trending sinistral brittle faults (D_4). Major easterly trending aeromagnetic lineaments, possibly fractures filled by Proterozoic mafic dykes, cut across the brittle faults. All greenstones are metamorphosed, with some rocks in the mid-amphibolite facies. Peak metamorphism took place pre- to syn- D_2 . Several episodes of granitoid intrusion are recognized in the region, with the most abundant granitoids intruded between c. 2.71 Ga and 2.67 Ga, during D_2 – D_3 .

Although LAKE GILES has been explored for gold, iron ore, and base metals, no significant deposits have been found.

KEYWORDS: Archaean, granite, greenstone, Southern Cross Province, Yilgarn Craton

Introduction

The LAKE GILES* 1:100 000 sheet (SH 50-8, 2838) forms the northeastern part of the BARLEE 1:250 000 sheet, and is bound by latitudes 29°30'S and 30°00'S, and longitudes 119°00'E and 119°30'E. It covers parts of the Yilgarn District of the Yilgarn Mineral Field, the Ularring District of the North Coolgardie Mineral Field, and the Mount Manning Range Nature Reserve.

Mapping was undertaken using 1:25 000-scale colour aerial photographs taken in October 1997 by the Western Australian Department of Land Administration (DOLA). Map compilation was assisted by Landsat imagery, aeromagnetic images (400 m line-space, flown by Kevron Geophysics Pty Ltd in 1997 and available for purchase

from the Australian Geological Survey Organisation), and information from mining and exploration company statutory reports. These reports can be accessed from the Geological Survey of Western Australia's (GSWA) Western Australian mineral exploration (WAMEX) open-file database.

LAKE GILES is approximately 650 km northeast of Perth and 350 km northwest of Kalgoorlie. The most direct access from Perth is via the Evanston–Bullfinch road, which joins the Great Eastern Highway at Southern Cross. From Kalgoorlie, the best access is via the Evanston–Menzies road, which crosses LAKE GILES 123 km west of Menzies.

There are no towns or homesteads on LAKE GILES (Fig. 1). The closest homestead is Diemals, located at the western end of the Evanston–Menzies road, about 20 km west of LAKE GILES. Mount Elvire Homestead is located 16 km north of LAKE GILES.

* Capitalized names refer to standard 1:100 000 map sheets, unless otherwise stated.

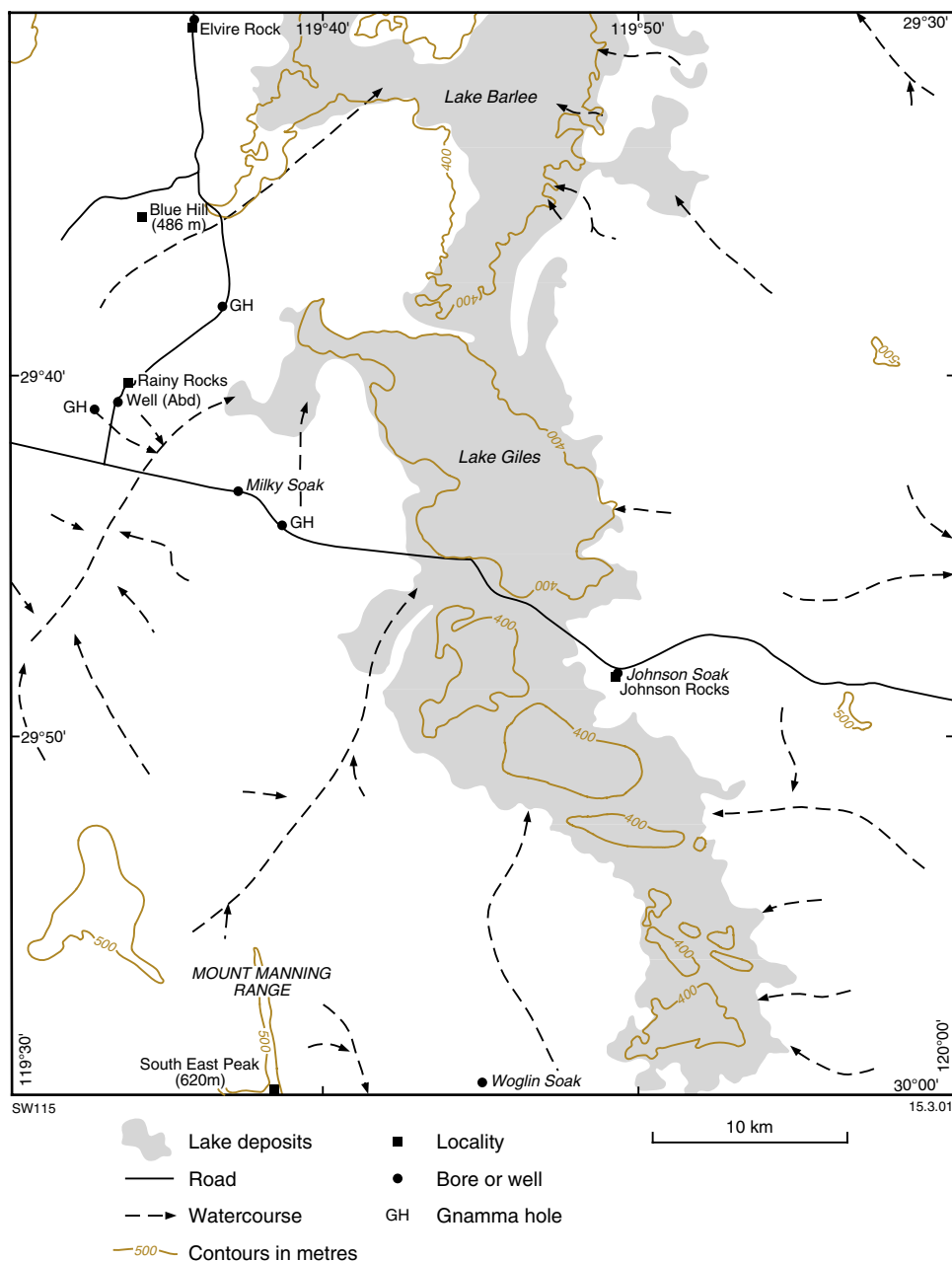


Figure 1. Physiography and access on LAKE GILES

Climate, physiography, and vegetation

The climate of LAKE GILES is semi arid, with a mean annual rainfall of about 275 mm*. Rain falls mainly in winter. However, the record for the highest daily rainfall is in December (127 mm) due to the peripheral influence of tropical storms from the northwest. Temperatures are moderate to high in the summer months with an average of 16.3 days per year over 40°C between November and March. The mean daily minimum

temperature ranges from 3.9 to 5.0°C between June and August.

The topography of LAKE GILES is flat to undulating, and is dominated by the Lake Giles and Lake Barlee playa-lake systems. The elevation in the playa systems is around 400 m, rising to 500 m in the surrounding sheetwash areas and sandplains (Fig. 1). Numerous banded iron-formation (BIF) ridges provide the greatest topographic relief. The highest point on LAKE GILES is South East Peak (620 m) in the Mount Manning Range, in the southwestern corner of the map sheet.

* Climatic data for Diemals Station is from the Commonwealth Bureau of Meteorology website, 2000.

LAKE GILES straddles two botanical regions defined by Beard (1990) — the Murchison Region to the north, and

the South Western Interzone to the south. The boundary between the regions is roughly coincident with the Evanston–Menzies road. Vegetation in both regions is dominated by mulga scrub (mostly *Acacia* spp.) covering the extensive sandplains, with local patches of low–medium woodland (mostly *Eucalyptus* spp.) found in sheetwash and alluvial areas. Mulga thickets are common on BIF ridges, and alluvial deposits adjacent to playa lakes are covered by salt-tolerant plants including *Haloscarcia*, *Atriplex*, *Maireana*, and *Frankenia*. There is a gradual increase in spinifex and decrease in *Eucalyptus* spp. from south to north on LAKE GILES.

Previous investigations

The earliest recorded exploration of the area was by the explorer Ernest Giles, who crossed the area in 1875 (Giles, 1889), and after whom Lake Giles was named. Following gold discoveries in the area around 1894, GSWA carried out brief geological investigations, recorded in Talbot (1912) and Woodward (1912). Matheson and Miles (1947) summarized the gold-mining groups and their production in the area. Other works that included geological mapping on LAKE GILES are theses by Porter (1971), Bettenay (1977), and Dalstra (1995). Walker and Blight (1983) mapped the BARLEE 1:250 000 sheet, the first published regional geological map of the area.

Precambrian geology

Regional geological setting

LAKE GILES lies within the Southern Cross Province of the Archaean Yilgarn Craton (Gee et al., 1981; Griffin, 1990; Myers and Swager, 1997). The Southern Cross Province is separated from the Eastern Goldfields Province to the east on the basis of differences in the range of rock types, age of the greenstone sequences, and the structural style. The boundary between the provinces is taken to be the Ida Fault, a regional-scale feature that lies about 100 km to the east of JOHNSTON RANGE (Fig. 2; Wyche, 1999).

The central part of the Southern Cross Province consists of c. 3.0 Ga, lenticular greenstone packages dominated by mafic volcanic rocks, with subordinate felsic and mafic intrusive rocks, and minor sedimentary and felsic volcanic rocks. This is the lower greenstone succession of Wyche et al. (in prep.). Greenstone packages or belts are separated by voluminous granitoid intrusions. To the west of LAKE GILES, the main greenstone succession is unconformably overlain by c. 2.73 Ga calc-alkaline volcanic and associated sedimentary rocks (Fig. 2; Hallberg et al., 1976; Riganti and Chen, in prep.; Wyche et al., in prep.). This is the upper greenstone succession of Wyche et al. (in prep.). The lower greenstone succession consists of quartzite as the lowest identified unit, exposed to the west on MULLINE (Wyche, 1999), and to the southwest on JACKSON (Riganti and Chen, in prep.), and includes high-Mg basalt, tholeiitic basalt, BIF, gabbro, and thin ultramafic units (Wyche et al., in prep.). However,

neither the lowermost quartzite of the lower greenstone succession, nor the upper greenstone succession are exposed on LAKE GILES. The five greenstone belts on LAKE GILES (Fig. 3; Griffin, 1990) are interpreted to contain only elements of the lower greenstone succession.

Greenstones on LAKE GILES have been subjected to multistage deformation with the development of an early, layer-parallel fabric that has been deformed during a protracted period of mainly east–west compression. Peak metamorphism coincided with a major period of granitoid intrusion between c. 2.71 Ga and 2.67 Ga (see Table 1).

Yerilgee greenstone belt

The exposed Yerilgee greenstone belt (Fig. 3) consists of a sequence of high-Mg basalt, at least 1 km thick, intruded by gabbro sills, and overlain by ultramafic rocks and BIF. High-Mg basalt and sedimentary rocks form the top of the sequence. The sedimentary package exposed in the Yerilgee belt (Fig. 3) may represent a restricted basin deposited unconformably over the main greenstone succession. However, the intercalation of gabbro with shale on the western edge of the sedimentary package suggests that it forms part of the main greenstone succession. Metamorphosed quartz–feldspar porphyry overlies high-Mg basalt in the western part of the belt, outcropping in the core of a major syncline (MGA 781700E 6690200N). This unit may be equivalent to the c. 2.73 Ga felsic volcanic rocks to the west on JACKSON and JOHNSTON RANGE (Nelson, in prep.).

The major structural feature of the Yerilgee belt is the large syncline on the eastern margin (Fig. 3), which plunges 40–60° to the northwest. It is slightly oblique to the main strike of the belt, possibly due to reorientation during D₃. Another major syncline is preserved in the west of the belt (Fig. 3), with the western limb truncated by a major fault. It is a tight, similar fold that plunges 30–50° to the north-northwest, parallel to the main strike of the belt. The granite–greenstone contacts are marked by major faults that are typically sheared and interpreted as faulted contacts. Two other major strike-parallel faults bound the major synclines, and probably truncate the local stratigraphy. These are crosscut by two northerly trending dextral faults attributed to D₄ (see **Structural geology**).

Mount Manning greenstone belt

Most of the Mount Manning greenstone belt lies on LAKE GILES. It consists of an approximately 1 km-thick sequence of variously metamorphosed basalt, overlain by chert and BIF, which is in turn overlain by high-Mg basalt and minor gabbro separated by BIF. The top of the sequence is marked by a thin ultramafic unit outcropping in the core of a major syncline in the south of the belt. The sequence is tectonically interleaved with granitoids towards the northern end of the belt. Calc-silicate units on the eastern margin are interpreted to be a result of post-kinematic, metasomatic alteration from the adjacent granitoids (see **Metamorphism**).

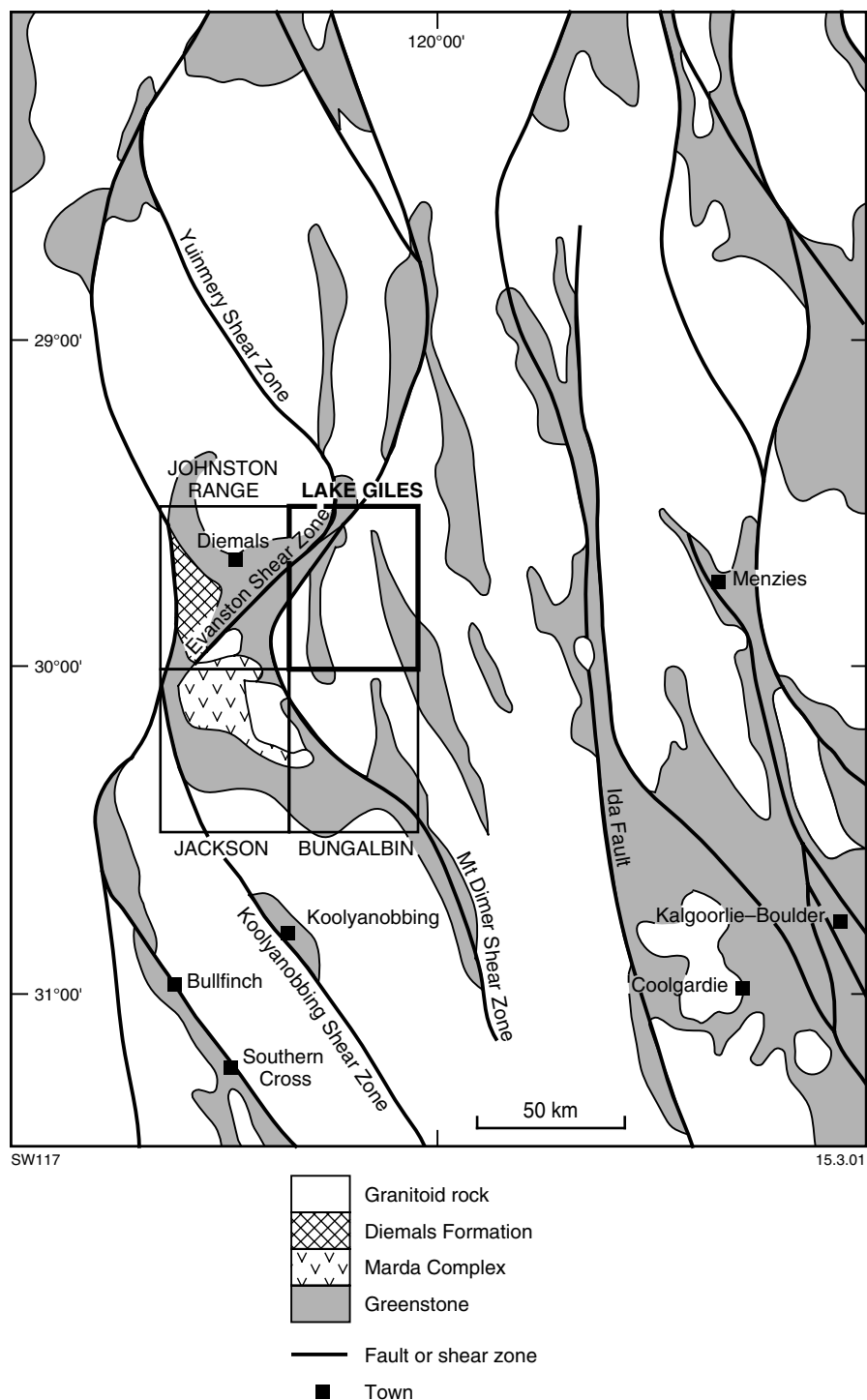


Figure 2. Regional geological setting of LAKE GILES (modified from Myers and Hocking, 1998)

The dominant structure in the Mount Manning greenstone belt is a large syncline that is best exposed in the south of the belt. It is an open to tight, similar fold plunging 40–60° to the north-northwest. The axial trace of the fold is oblique to the main strike of the belt and is interpreted to be a D₂ fold reoriented during D₃. Arcuate faults bound the western margin of the belt and merge

with the Evanston Shear Zone in the northern part of the belt (Fig. 3).

South Elvire greenstone belt

The South Elvire greenstone belt consists of two greenstone packages separated by the Evanston Shear

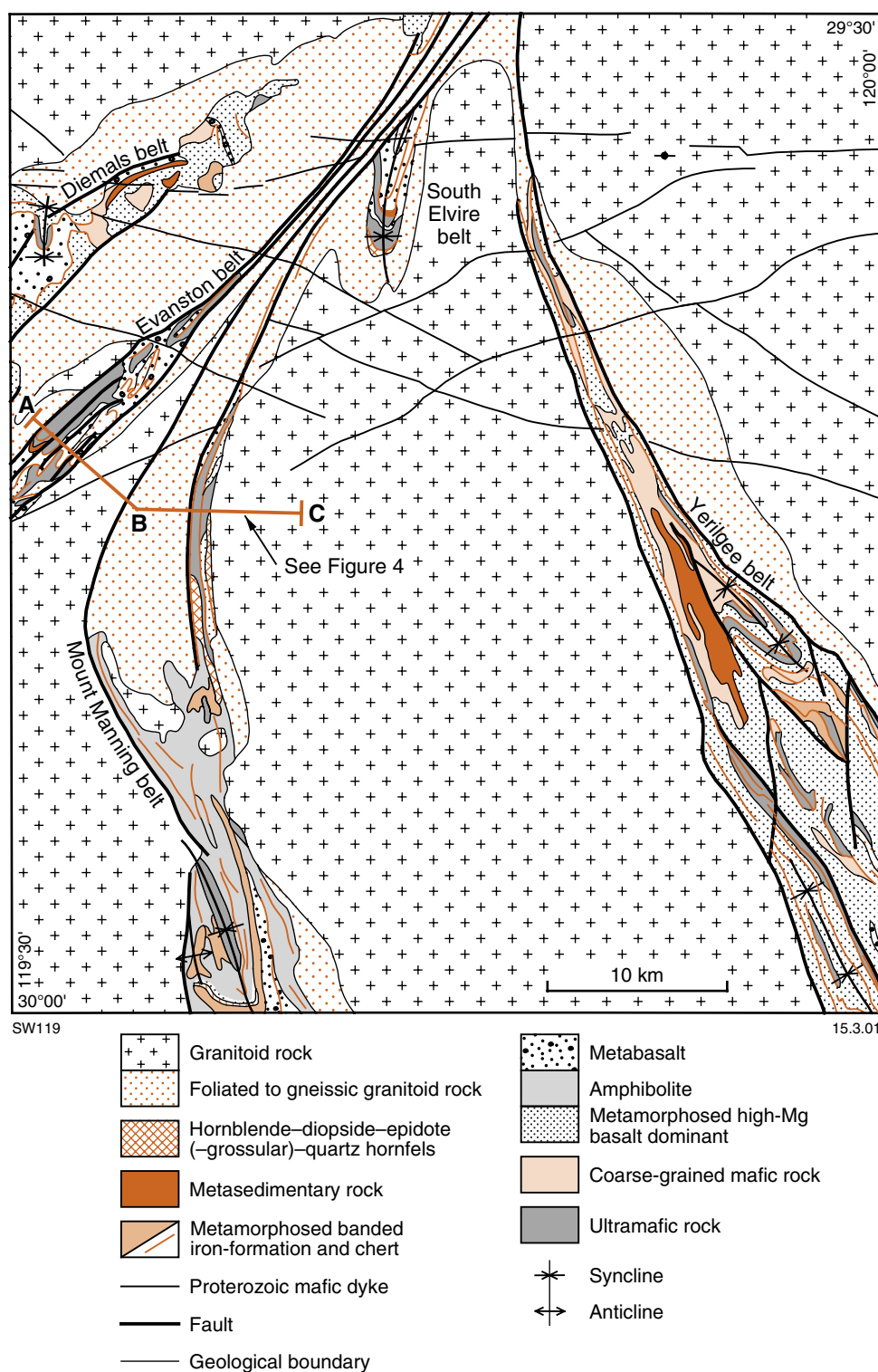


Figure 3. Interpreted solid geology of LAKE GILES

Zone, and surrounded by granitoids. The southern package is entirely contained within LAKE GILES and consists of medium- to high-grade metamorphosed calc-silicate rock overlain by ultramafic rock, tholeiitic basalt, BIF, and minor pelitic schist. The structure of the belt is dominated by a large syncline, with a slightly curved fold axis, which plunges 30–50° to the north.

The northern package is only partly exposed on LAKE GILES where it contains steeply dipping BIF overlain by intercalated ultramafic rock and tholeiitic basalt. The eastern side of the belt lies within the Evanston Shear Zone, where it is intruded by granitoid sills and quartz veins parallel to the shear zone. This granitoid is strongly foliated to gneissic, contains numerous amphibolite

Table 1. Geological evolution of LAKE GILES

<i>Age</i>	<i>Deformation event</i>	<i>Geology</i>
c. 3.0 Ga		Deposition of the lower greenstone succession; burial/seafloor metamorphism (M ₀)
	D ₁	Layer-parallel, penetrative foliation; thrusting and tight to isoclinal folding recognized to the west; low-grade metamorphism (M ₁)
	D ₂	Initiation of east–west compressional regime Upright to inclined, tight to isoclinal folding; open, upright folding to the west
c. 2.73 Ga		Granitoid intrusion, felsic volcanism, and deposition of clastic sedimentary rocks (upper greenstone succession to the west)
c. 2.7 – 2.67 Ga	D ₃	Granitoid intrusion; peak metamorphism (M ₂)
Pre-c. 2.65 Ga		Development of major northeasterly and northwesterly trending shear zones; reorientation of D ₂ structures
	D ₄	North-northeasterly and east to east-southeasterly trending brittle faults developed during east-northeast – west-southwest compression Intrusion of easterly to northeasterly trending mafic and ultramafic dykes along crosscutting fractures

enclaves, and is locally migmatized. The northernmost part of the belt extends onto MARMION (Chen and Greenfield, in prep.).

Diemals greenstone belt

Only the northeastern extension of the Diemals greenstone belt is preserved on LAKE GILES, with the remainder on JOHNSTON RANGE (Wyche et al., 2000). On LAKE GILES, the belt is deeply weathered and lateritized, and greenstone units are poorly exposed. The belt is complexly deformed, with irregular granite–greenstone contacts. The local sequence consists of tholeiitic basalt and high-Mg basalt, overlain by minor ultramafic and sedimentary rocks. Banded iron-formation units are intercalated throughout. In this area, it is very difficult to decipher a reliable stratigraphy due to the high degree of deformation and weathering.

Although the Diemals greenstone belt is complexly deformed, it has dominantly northerly trending folds, including a large, box-walled syncline defined by BIF units. The belt is partly bound by discontinuous faults that are associated with quartz veining.

Evanston greenstone belt

The northeasterly trending Evanston greenstone belt is only partly exposed on LAKE GILES. It contains strongly deformed, steeply dipping greenstone units metamorphosed to amphibolite facies. Because of tectonic disruption, a reliable stratigraphic succession for the belt, exposed on LAKE GILES, has not been established. The southwestern end of the belt, exposed on JOHNSTON RANGE, is less deformed, and a generalized sequence consists of

tholeiitic basalt overlain by high-Mg basalt and ultramafic rocks, with a less than 100 m-thick BIF unit at the top of the exposed succession. Minor gabbro, pelitic schist, and thin BIF lenses are intercalated throughout.

The Evanston greenstone belt on LAKE GILES is contained within the northeasterly trending Evanston Shear Zone. The greenstones consist of a series of westerly verging, partly truncated folds that plunge moderately to the southwest. A strong foliation in the greenstone units is parallel to a series of faults that are considered to be part of the Evanston Shear Zone. Rotated porphyroclasts and S–C fabrics in the foliated granitoid adjacent to the western granite–greenstone contact indicate a right lateral sense of movement attributed to D₃ deformation along the Evanston Shear Zone (see **Second deformation**). The granite–greenstone contact is sharp along the western margin of the belt, but diffuse on the eastern margin.

Archaean rock types

Metamorphosed ultramafic rocks (*Au*, *Auk*, *Aup*, *Aur*, *Aus*, *Aut*)

Metamorphosed ultramafic rocks are found in all the exposed greenstone belts on LAKE GILES. In most cases, the outcrops are small and deeply weathered. Undivided ultramafic rock (*Au*) is locally covered by silica caprock (*Rzu*), and is identified by remnants of talc, tremolite, and chlorite in the rock. Undivided ultramafic rocks are found almost exclusively on eroded slopes immediately below BIF ridges.

Metakomatiite (*Auk*) is preserved in one narrow outcrop in the Yerilgee belt (MGA 783500E 6688500N) and contains relict pseudomorphs of olivine blades

between 1 and 8 cm in length. The unit consists of serpentine and tremolite with minor chlorite and magnetite. Some serpentinite (*Aus*) outcrops in the Mount Manning belt (MGA 753000E 6683500N) also have rare relict spinifex textures, but are dominantly massive serpentine with minor talc and magnetite.

There are substantial metaperidotite (*Aup*) outcrops in the South Elvire and Yerilgee belts. In the Yerilgee belt, these outcrops are adjacent to high-Mg basalt outcrops, whereas in the South Elvire belt they are found between amphibolite outcrops. A close association of metaperidotite with BIF is common on LAKE GILES. Metaperidotite is also recognized in percussion drillchips from mineral-exploration drillholes within the Mount Manning belt (MGA 752500E 6705200N). Metaperidotite is typically foliated in outcrop, and has a characteristic dark-brown weathering rind. Fresh surfaces display cumulate textures (dominantly mesocumulate), with rounded pseudomorphs of olivine crystals up to 1 cm in diameter. Much of the olivine has been pseudomorphed by antigorite and talc. In thin section, minor orthopyroxene and clinopyroxene are interstitial to the former olivine grains, and chlorite and magnetite are also present as minor secondary minerals.

Deeply weathered, schistose outcrops of tremolite–chlorite(–talc) schist (*Aur*) and talc–tremolite(–chlorite) schist (*Aut*) are common in all greenstone belts on LAKE GILES except the Diemals belt. They are typically found in narrow, subdued outcrops adjacent to BIF ridges.

Metamorphosed, coarse-grained mafic rocks (*Ao*, *Aog*, *Aogf*)

Coarse-grained mafic rocks are significant components of the Diemals and Yerilgee greenstone belts on LAKE GILES. They have undergone medium grade metamorphism, with the major effect being the conversion of pyroxene phenocrysts to actinolite or, more commonly, blue–green hornblende. They are interpreted as sills intruded into the lower greenstone sequence, on the basis of their layer-parallel distribution and coarse grain size. Some outcrops contain megacrystic plagioclase (e.g. MGA 753300E 6727700N). However, rare spinifex textures, containing amphibole needles (up to 8 cm long) after pyroxene (e.g. MGA 783800E 6693600N), suggest rapidly chilled portions of these units.

Deeply weathered, coarse-grained mafic rock (*Ao*) is distinguished from fresh, medium- to coarse-grained metagabbro (*Aog*), which consists mainly of blue–green hornblende, plagioclase, and magnetite. Common minor minerals include actinolite, sphene, biotite, and epidote. Strongly foliated metagabbro (*Aogf*) has been distinguished from metagabbro (*Aog*) by the presence of a pervasive foliation. This unit outcrops in the Diemals belt, south of Blue Hill (MGA 749500E 6723500N).

Metamorphosed, fine-grained mafic rocks (*Ab*, *Aba*, *Abe*, *Abf*, *Abg*, *Abm*, *Abmf*, *Abr*, *Abv*)

Fine-grained mafic rocks are common in all greenstone belts on LAKE GILES. They contain features that indicate

an extrusive origin, such as pillow structures and amygdalites. They have been variously metamorphosed to between lower greenschist and lower amphibolite facies. Most mafic rock types have been deformed, with the dominant foliation ascribed to S_2 – S_3 (see **Structural geology**). Deeply weathered outcrops of undivided mafic rock (*Ab*) form adjacent to BIF ridges in the Yerilgee belt. This unit is distinguished from weathered, strongly foliated mafic rock (*Abf*) by the presence of a pervasive foliation.

Metabasalt (*Abv*) is characterized in the field by hillocks of dark-green, blocky subcrop and outcrop. Fresh surfaces reveal a fine-grained, dark-green rock, commonly containing light-coloured, quartz-filled amygdalites. From thin sections, metabasalt is typically composed of decussate actinolite bundles, with minor plagioclase, magnetite, and khaki-coloured hornblende. Common accessory minerals include chlorite, sphene, epidote, and quartz. Metabasalt that has undergone pervasive epidote alteration (*Abe*) has been mapped separately in the Yerilgee belt (MGA 784500E 6690300N) and the Diemals belt (MGA 748500E 6724700N).

High-Mg basalt (*Abm*), the most abundant fine-grained mafic rock on LAKE GILES, is recognized in the field by the presence of common variolitic and pyroxene-spinifex textures. Pyroxene in these rocks has been pseudomorphed by fibrous actinolite or tremolite, and the common assemblage contains colourless to light-green tremolite–actinolite needles within a fibrous, green actinolite groundmass, and minor plagioclase and quartz. Where high-Mg basalt has been pervasively foliated, it has been shown as a separate unit (*Abmf*). In the Diemals belt, pillow-lava structures are preserved in extensive, foliated high-Mg basalt outcrop (e.g. MGA 754500E 6729200N), but the younging direction is ambiguous. Narrow (0.05 – 1.0 mm wide) veins in high-Mg basalt and foliated high-Mg basalt are commonly filled by clinozoisite, plagioclase, and quartz.

Amphibolite (*Aba*) represents fine-grained mafic rock that has undergone amphibolite facies (medium-grade) metamorphism. This unit forms mostly on the margins of the greenstone belts, but is present throughout the South Elvire and Evanston belts. It is characterized in the field by a medium-grained, dark-green, amphibole-dominated rock that is commonly foliated. In thin section, amphibolite consists of blue–green hornblende, actinolite, plagioclase, quartz, and magnetite, with minor occurrences of clinopyroxene (mostly in veins), garnet, sphene, and biotite. In the northern part of the South Elvire belt (MGA 766000E 6734000N), amphibolite is interleaved with foliated granitoid rock (*Abg*) at outcrop scale.

In the southern part of the Yerilgee and Evanston belts (e.g. MGA 742000E 6708000N), strongly foliated, tremolite- and chlorite-rich rock (*Abr*) is interpreted to be derived from high-Mg basalt, based on adjacent or along-strike association.

Metamorphosed felsic rocks (*Afp*, *Afx*)

There are two isolated outcrops of metamorphosed felsic rocks on LAKE GILES. In the Yerilgee belt, a narrow outcrop

of felsic porphyry (*Afp*) occupies the core of a major syncline (MGA 781800E 6690300N). The felsic porphyry contains dominantly plagioclase phenocrysts set in a fine-grained groundmass of quartz, plagioclase, green hornblende, and K-feldspar. Interstitial garnet and black spinel replace hornblende and feldspar throughout the rock.

In the Diemals belt, east of the Lake Barlee road (MGA 754000E 6727600N), a narrow sill of brecciated felsic porphyry (*Afx*) is found in almost continuous outcrop over a strike length of about 2 km. The porphyry contains cobble-sized, angular fragments that commonly display a jigsaw fit, suggesting that the unit was hydraulically fractured. In thin section, the mineralogy consists of plagioclase and K-feldspar phenocrysts set within a highly recrystallized, aphanitic groundmass of quartz, plagioclase, blue-green hornblende, and sphene.

Metasedimentary rocks (*Ash*, *Asq*, *Ass*, *Ac*, *Acī*)

Clastic metasedimentary rocks (*Ash*, *Asq*, *Ass*) are found as minor components of all greenstone belts on LAKE GILES, with the exception of the Mount Manning greenstone belt. The most common units are narrow, isolated bands of metamorphosed shale (*Ash*) that form subdued outcrops, commonly adjacent to BIF ridges. The shale is typically schistose and crenulated, with a foliation defined by muscovite, chlorite, and biotite. These schists may also contain medium- to coarse-grained andalusite, staurolite, garnet, or sillimanite porphyroblasts (see **Metamorphism**). An isolated unit of quartzite (*Asq*) in the Yerilgee belt (MGA 781000E 6697300N) consists of fine- to medium-grained, recrystallized quartz with expansion cracks on one exposed surface. North of the quartzite unit (MGA 780000E 6699600N), a narrow outcrop of subarkosic metasandstone (*Ass*) contains subrounded to rounded quartz and feldspar clasts, and minor muscovite. Sericitization of the feldspars is pervasive. The metasandstone is interbedded with rare metasiltstone and metamorphosed, pebbly sandstone layers.

Banded iron-formation (*Acī*) is very common in all greenstone belts on LAKE GILES, where it forms the most resilient outcrops and most prominent magnetic anomalies. The BIF units typically consist of centimetre-scale intercalations of medium-grained, sub- to euhedral magnetite and fine-grained, recrystallized quartz (mostly chert). Many BIF units contain small-scale slump structures and growth faults. One unit in the Evanston belt (MGA 747300E 6712200N) contains thin bands of clinopyroxene and pale hornblende between goethite and quartz laminations, suggesting either a protolith mafic component in this unit or pervasive alteration. Rarely, where siliceous layers dominate BIF outcrops, they have been designated as chert (*Ac*). Examples of this are in the Mount Manning (MGA 752400E 6702400N) and South Elvire belts (MGA 763300E 6722600N).

Calc-silicate rocks (*Ahhx*)

Calc-silicate granofels (*Ahhx*) on the margins of the South Elvire and Mount Manning greenstone belts has been

metamorphosed to amphibolite facies. The low outcrops are characterized by a dark-brown weathering rind. In some cases, calc-silicate granofels appears to grade into other rock types along strike, and extensive vein networks are observed in the most altered rocks. Therefore, a metasomatic origin for the calc-silicate granofels is inferred, and this is supported by the close proximity of this unit to granitoid contacts. Mineralogy is dependent on the protolith, and ranges from diopside-grossular-epidote granofels to almost pure hornblende. Where BIF units have been metasomatized, they consist of centimetre-scale, coarse-grained layers of quartz within hornblende, magnetite, quartz, and plagioclase layers. Vein mineralogy commonly consists of diopside, plagioclase, quartz, and blue-green hornblende. Accessory minerals include rutile, sphene, epidote, and perovskite.

Granitoid rocks (*Ag*, *Agf*, *Agm*, *Agn*)

Granitoid rocks comprise approximately 75% of LAKE GILES, and are dominated by biotite-bearing monzogranite. Outcrop is very sparse, and consists mainly of weathered pavements, but also includes large tors and whalebacks. Where weathering has precluded feldspar identification, the granitoid outcrop has been classified as undivided (*Ag*).

Most monzogranite (*Agm*) outcrops preserve a weak, near-vertical foliation defined by the alignment of biotite, feldspar phenocrysts, and minor phases such as pegmatite and mafic enclaves. Although the strike of this fabric can vary within the same outcrop (e.g. MGA 759500E 6706300N), most monzogranite outcrops have a northerly trending grain. This is inferred to be mainly due to subsolidus magmatic deformation, as thin sections of these rocks indicate little crystal deformation. In contrast, pavement-style outcrops of gneissic granitoid (*Agn*) contain a strong tectonic fabric, defined by flattening of phenocrysts and attenuated compositional layering, which is parallel to adjacent greenstone contacts. In the Evanston belt, some localities have kinematic indicators such as rotated and stretched porphyroclasts, and S-C and C-C fabrics (see **Third deformation**). Migmatization has affected the gneissic granitoids north of Milky Soak (MGA 755300E 6714000N) and within the South Elvire belt (MGA 765500E 6732300N). Outcrops in these areas contain schollen structures, with rafts of orthogneiss in a medium-grained, monzogranitic leucosome.

The mineralogy of the monzogranites typically comprises microcline, albitic plagioclase, quartz, and biotite. Accessory minerals include zircon, opaque oxides (mainly magnetite), sphene, apatite, allanite, and fluorite. Secondary alteration minerals include sericite (after feldspar), chlorite (after biotite), and rare epidote. Microcline (<8 cm), plagioclase (<6 cm), and more rarely quartz (<4 cm) form sub- to euhedral phenocrysts.

Rare granite-greenstone contacts preserve evidence for both intrusive and faulted contact relationships. In the southeastern Evanston belt, strongly foliated granitoid rock (*Agf*) contains amphibolite enclaves and irregular boundaries suggesting an intrusive contact. However, in the northwestern Evanston belt, the contact is straight and

associated with intense shearing, and is interpreted as a faulted contact. Outcrop relationships and aeromagnetic interpretation suggest that the majority of the granite–greenstone contacts on LAKE GILES are faulted (Figs 3, 4, and 5).

Monzogranite at Johnston Rocks (MGA 772820E 6699540N) has been dated using sensitive high-resolution ion microprobe (SHRIMP) U–Pb zircon geochronology, giving an estimated crystallization age of 2693 ± 4 Ma (Nelson, 2000), and strongly deformed monzogranite from an outcrop within the Evanston Shear Zone (MGA 742470E 6710180N) has a U–Pb SHRIMP zircon age of 2654 ± 6 Ma (Nelson, in prep.). Other SHRIMP U–Pb zircon dating in the region indicates a period of widespread granitoid intrusion between c. 2.71 Ga and c. 2.67 Ga (Nelson, 1999, 2000, in prep.).

Quartz veins (q)

Quartz veins are common on LAKE GILES, and intrude all exposed rock types. Several generations are recorded at outcrop scale, and some pre-date major folding (D_2). At the map scale, large quartz veins, up to 40 m thick, are traceable over several hundred metres. Large quartz veins within the greenstone sequences are commonly parallel to strike. However, in the northeastern part of LAKE GILES, a distinct vein set trends north-northeast, and is associated with late (D_4) dextral faulting. Another large-scale set trends east (e.g. MGA 748700E 6695400N), and is also associated with late faults (see **Structural geology**).

Most quartz veins contain massive to crystalline quartz, are laminated on a decimetre scale, and are cataclastically deformed. The best examples of quartz-vein laminations are found in the Evanston Shear Zone, where they show evidence of multiple stages of veining (Fig. 6).

Structural geology

Rocks on LAKE GILES have been subjected to three major penetrative deformation events with associated metamorphism, and at least two further brittle deformation events (Table 1). Although evidence for each event is found on LAKE GILES, the best overprinting relationships in the region are found on the adjacent JOHNSTON RANGE sheet (Wyche et al., 2000). Dalstra (1995), Dalstra et al. (1999), Greenfield and Chen (1999), Chen et al. (2001), and Wyche et al. (in prep.) further discussed the regional structural and metamorphic history of the area.

First deformation (D_1)

The first deformation event recognized on LAKE GILES is a rarely observed, penetrative foliation that has been refolded and crenulated by later deformation. This is best preserved in the South Elvire belt (MGA 763400E 6722500N), where a metamorphosed shale unit has been deformed in the core of a D_2 – D_3 syncline. In this example, crenulated muscovite schist contains a layer-

parallel foliation (S_1) that dips moderately to the north. The crenulation axis plunges moderately to the north, and is interpreted to be parallel to the D_2 – D_3 fold axis. Sillimanite porphyroblasts, grown during peak metamorphism, overprint the foliation and define a lineation that is also parallel to the D_2 – D_3 fold axis.

The D_1 deformation has produced layer-parallel, tight to isoclinal folds on JOHNSTON RANGE to the west (Wyche et al., in prep.), and thrust faults on BUNGALBIN to the southwest (Riganti and Chen, in prep.). The timing of D_1 is unclear. However, it pre-dates clastic sedimentary rocks of the Diemals Formation, which were deposited after c. 2.73 Ga on JOHNSTON RANGE (Wyche et al., in prep.).

Dalstra et al. (1999) estimated pressure–temperature (P–T) conditions of less than 400°C and 220 MPa during D_1 , based on actinolite–albite pairs in mafic rocks from the central Diemals belt on the adjacent JOHNSTON RANGE sheet.

Second deformation (D_2)

Upright to inclined, ductile folding throughout the greenstone sequences is mostly attributed to the second deformation event (D_2). These folds formed on all scales, and are best preserved within BIF units. Fold morphology is characterized by north-northwesterly trending, tight to isoclinal, similar- to chevron-style, moderately plunging fold types. Inclined parasitic folds are common on the limbs of map-scale folds, which are dominantly synformal. A pervasive penetrative foliation is mainly northerly trending, parallel or axial planar to D_2 folds, and is defined by peak metamorphic minerals in most rock types. Therefore, it is inferred that peak metamorphism (M_2) was broadly synchronous with D_2 . This deformation is the result of east–west compression. Timing of the onset of D_2 is uncertain, but it may have been active prior to, or early during the deposition of the clastic sedimentary rocks of the Diemals Formation on JOHNSTON RANGE after c. 2.73 Ga (Wyche et al., in prep.).

Dalstra et al. (1999) estimated P–T conditions of 540°C and less than 400 MPa during D_2 , based on hornblende–plagioclase pairs in amphibolite from the Evanston belt on the adjacent JOHNSTON RANGE sheet.

Third deformation (D_3)

The third deformation (D_3) involved strike-slip movement on major shear zones and reorientation of D_2 fold axes. Chen et al. (2001) argued that this was due to protracted westward-directed compression. Major faults and shear zones are shown on Figure 3. Most of the regional-scale faults occur at or near granite–greenstone contacts, probably due to rheological differences between these rock types. Synclinoria attributed to D_2 in the Yerilgee and southern Mount Manning belts were reorientated during D_3 to become north-northwesterly trending. In contrast, folds in the Evanston and South Elvire belts now trend northeast to north-northeast (Greenfield and Chen, 1999).

The most prominent D_3 structure on LAKE GILES, the Evanston Shear Zone, cuts across the northwestern

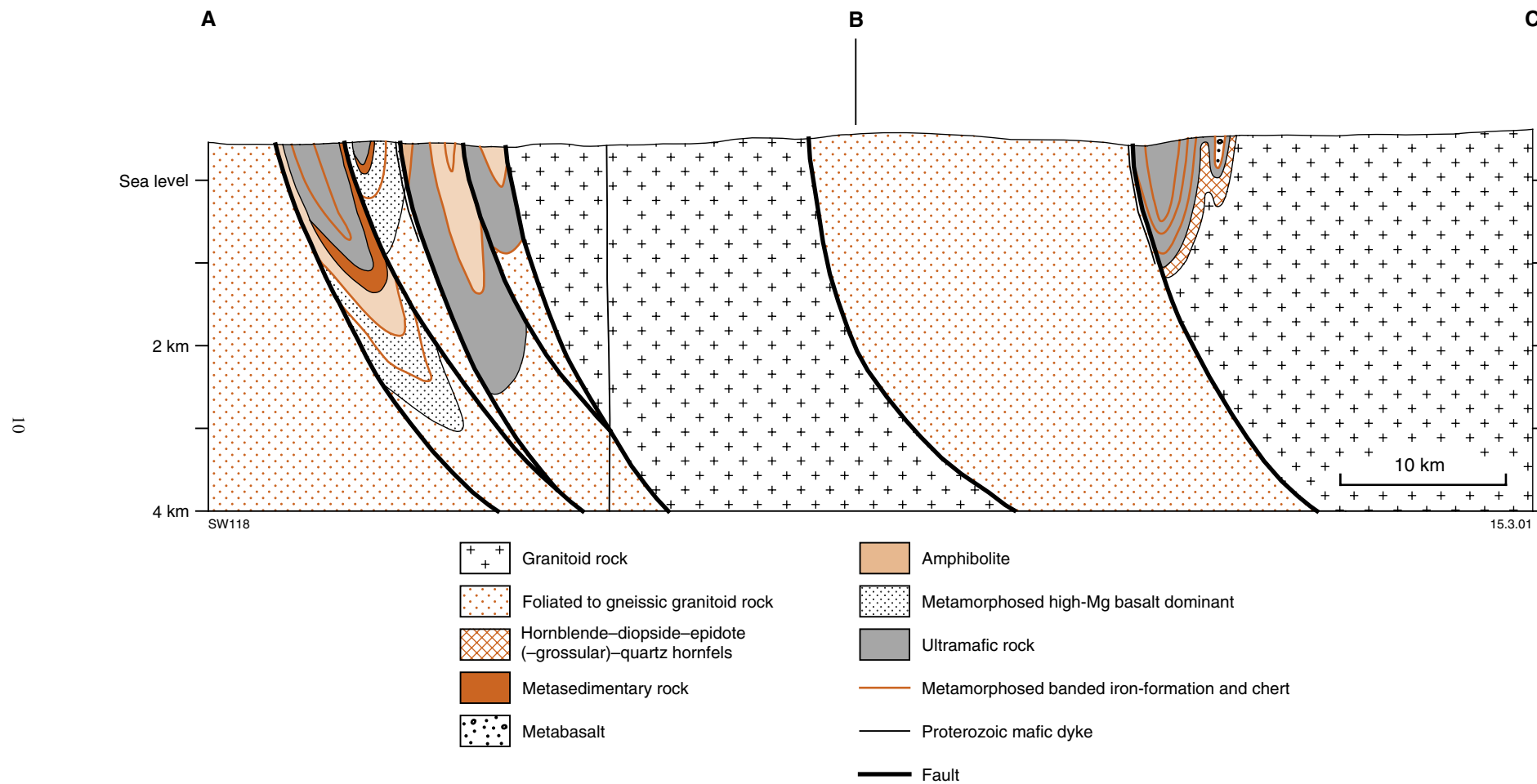


Figure 4. Diagrammatic cross section through the Evanston belt. See Figure 3 for location of section line



Figure 5. Total magnetic intensity image of LAKE GILES based on 400 m line-spaced data

quadrant of the sheet (Fig. 3), where it is a northeasterly trending shear zone that dissipates into a number of discrete faults. The most compressed section of the shear zone on LAKE GILES is about 1 km thick (MGA 759000E 6723000N), based on aeromagnetic interpretation. It has deformed both granitoid and greenstone rocks, reducing the Evanston belt to a series of inclined synforms separated by steep southeasterly dipping faults (Fig. 4). Abundant laminated quartz veins intrude into this compressed section of the shear zone (Fig. 6). Rotated and stretched feldspar porphyroclasts, along with S–C and C–C fabrics, indicate right lateral movement along the Evanston Shear Zone (Fig. 7). Mineral lineations in gneissic granitoid are subhorizontal, and defined by stretched feldspar and quartz phenocrysts. The best examples on LAKE GILES are within strongly foliated granitoid rock (e.g. MGA 742500E 6710100N).

Strongly deformed monzogranite from an outcrop within the Evanston Shear Zone (MGA 742470E 6710180N) has a U–Pb SHRIMP age of 2654 ± 6 Ma

(Nelson, in prep.), indicating that D_2 was still active at this time.

Fourth deformation (D_4)

Numerous large-scale, north-northeasterly and east to east-southeasterly trending brittle faults (D_4) cut across granitoid rocks, greenstones, and D_3 structures. These are best observed as linear, magnetically low anomalies on aeromagnetic images (Fig. 5), where they appear to cut across granitoid areas. A prominent set cuts through the Yerilgee belt and coincides with narrow quartz veins outcropping to the northeast (e.g. MGA 784000E 6710700N). Quartz also infills the west-southwesterly trending fault set (e.g. MGA 773000E 6685800N). The north-northeasterly trending faults have brittle dextral offsets of up to 200 m, whereas the east-southeasterly trending faults have sinistral offsets of up to 50 m. They probably represent a conjugate set, with an approximately east-northeast – west-southwest axis of compression.



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Figure 6. Quartz vein within the Evanston Shear Zone (AMG 757300E 6722000N), showing evidence of multiple veining episodes



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Figure 7. Stretched and rotated porphyroclasts in strongly foliated granitoid rock (Agf) from the Evanston greenstone belt (AMG 742500E 6710100N) showing dextral sense of movement

Later deformation

Prominent, regional-scale fractures in the north of LAKE GILES record the final major deformation events observed in the area. There is no surface expression of these structures and they are interpreted from aeromagnetic data (Fig. 5). Three trends of distinct fracture sets are recognized: east–west, east–northeast, and east–southeast. The easterly and east–southeasterly trending sets are imaged as magnetic high anomalies, whereas the east–northeasterly trending set appear as magnetic lows. They clearly crosscut D_4 structures, and are interpreted to relate to craton-scale, Proterozoic dyke swarm events (Hallberg, 1987), but the number of events and their absolute ages are unknown.

Metamorphism

All greenstones on LAKE GILES have been metamorphosed. Peak metamorphic conditions ranged between prehnite–pumpellyite facies and upper amphibolite facies, and there is also evidence for greenschist facies retrogression in places. The metamorphic map of LAKE GILES (Fig. 8) shows mineral foliation relationships and thin-section localities. Metamorphic grades have been determined mainly by thin-section mineralogy, and reflect the domain subdivisions used by Binns et al. (1976) and Ahmat (1986).

The distribution of metamorphic grade is similar to previous maps produced by Ahmat (1986), Dalstra (1995), and Dalstra et al. (1999). The main features are a broad decrease in metamorphic grade towards the centre of the greenstone belts, and relatively higher grades on the eastern margins of the belts. The Evanston and South Elvire belts contain medium- to high-grade rocks throughout, possibly related to their association with the Evanston Shear Zone. Detailed examination of metamorphic grade distribution indicates patchy low-grade domains in the Diemals belt that extend to the northern granite–greenstone margin, and a domain of very low grade rocks, mainly sericite-bearing shale and chlorite- and albite-bearing high-Mg basalt, in the centre of the Yerilgee belt. Higher grade (mid- to upper-amphibolite facies), sheared amphibolites on the eastern margin of the Evanston belt contain blue–green hornblende and rare clinopyroxene. Locally, a small area in the South Elvire belt (MGA 763400E 6722500N) contains garnet–biotite–sillimanite schist and hornblende–garnet amphibolite.

Mineral–foliation relationships imply that metamorphism in the medium- to high-grade domains occurred in at least two stages, and that the peak metamorphic event was probably diachronous between domains (Dalstra et al., 1999). The very low grade domain in the centre of the Yerilgee belt contains randomly oriented metamorphic minerals formed in prehnite–pumpellyite to lower greenschist facies conditions. This static style of metamorphism (M_0), present throughout the Southern Cross Province, has been attributed to pre-tectonic, high temperature isotherms (Ahmat, 1986) or sea-floor metamorphism (Dalstra et al., 1999).

The muscovite foliation observed in the South Elvire belt (Fig. 9a) is the earliest metamorphic fabric observed

on LAKE GILES, and corresponds to the first metamorphic event (M_1). This foliation has been crenulated and overprinted by an M_2 garnet–biotite–sillimanite assemblage (Fig. 9b). Sillimanite prisms formed during M_2 are parallel to the plunge of the S_2 crenulation and the D_2 – D_3 fold axis (Fig. 10). However, some garnet porphyroblasts overprint the biotite foliation (Fig. 9c), suggesting that M_2 in the South Elvire belt was a relatively long-lived event with high heat flow, and active before, during, and after D_2 – D_3 .

The narrow, high-grade domain in the Evanston belt also contains evidence of pre- to syn-kinematic M_2 relationships between porphyroblasts and the foliation, whereas the medium-grade domains of the Evanston and Diemals belts contain deformed, peak metamorphic andalusite, staurolite, and garnet porphyroblasts, as summarized on Figure 8. Some domain boundaries appear convoluted and terminated, possibly as a result of deformation after peak metamorphism.

Inferred retrograde metamorphism in samples from LAKE GILES, mostly at greenschist-facies conditions, included sericitization and saussuritization of feldspars, chloritization, and talc–carbonate alteration of ultramafic schists. Calc–silicate alteration in the Mount Manning and South Elvire belts has a hornfelsic to granoblastic texture, and appears to have a metasomatic origin.

Cainozoic geology

LAKE GILES is covered by extensive regolith deposits as a result of prolonged weathering. The regolith mapping has been classified into relict (residual) and depositional regimes based on the Residual–Erosional–Depositional (RED) scheme of Anand et al. (1993), with modifications by Hocking et al. (2001).

Residual units (*Rd*, *Rf*, *Rgp_g*, *Rk*, *Rzu*)

Undivided, lateritic duricrust (*Rd*) is mostly covered by a thin layer of quartz sand and pisolite nodules (*SI*). It covers extensive areas of LAKE GILES, mostly underlain by kaolinitized granitoid rock. Only in breakaways can the profile of the duricrust be observed, where it consists of siliceous to slightly ferruginous duricrust underlain by saprolite. The most easily accessible example of a duricrust profile is found west of the Mount Manning Range (MGA 751000E 6705300N).

Siliceous and ferruginous duricrust (*Rf*) outcrops extensively over greenstone rocks, particularly over weathered BIF. This unit is clearly identified on airphotos by a medium-brown hue and slight relief above the colluvial units. The caprock, which consists of hematitic ironstone, is commonly reworked.

Areas of sparse, deeply weathered to lateritized granitoid rock, associated with probable residual quartzofeldspathic sand (*Rgp_g*), represent the transition between undivided duricrust and weathered granitoid outcrop. On LAKE GILES, residual granitoid areas are commonly surrounded by sheetwash.

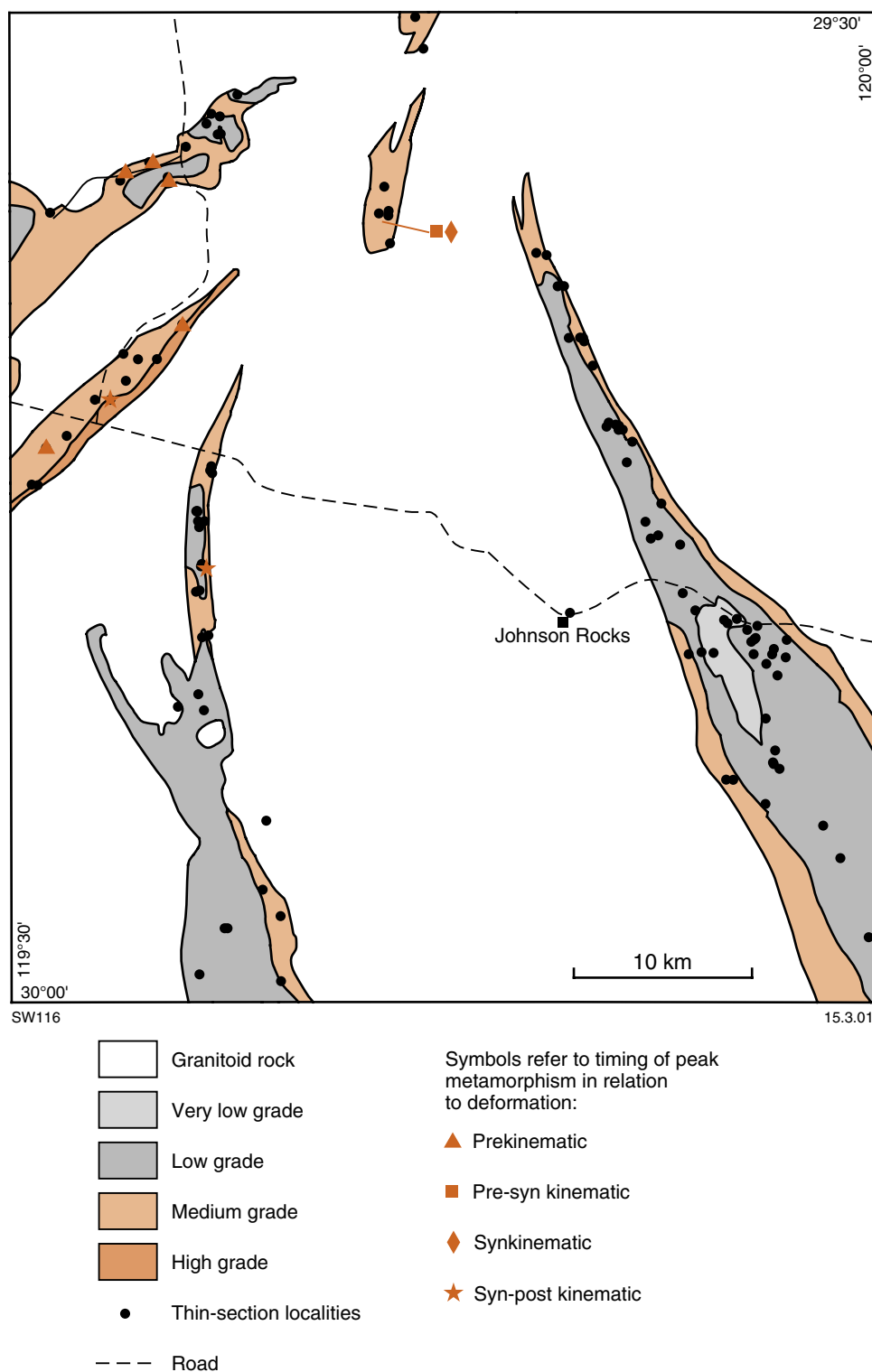
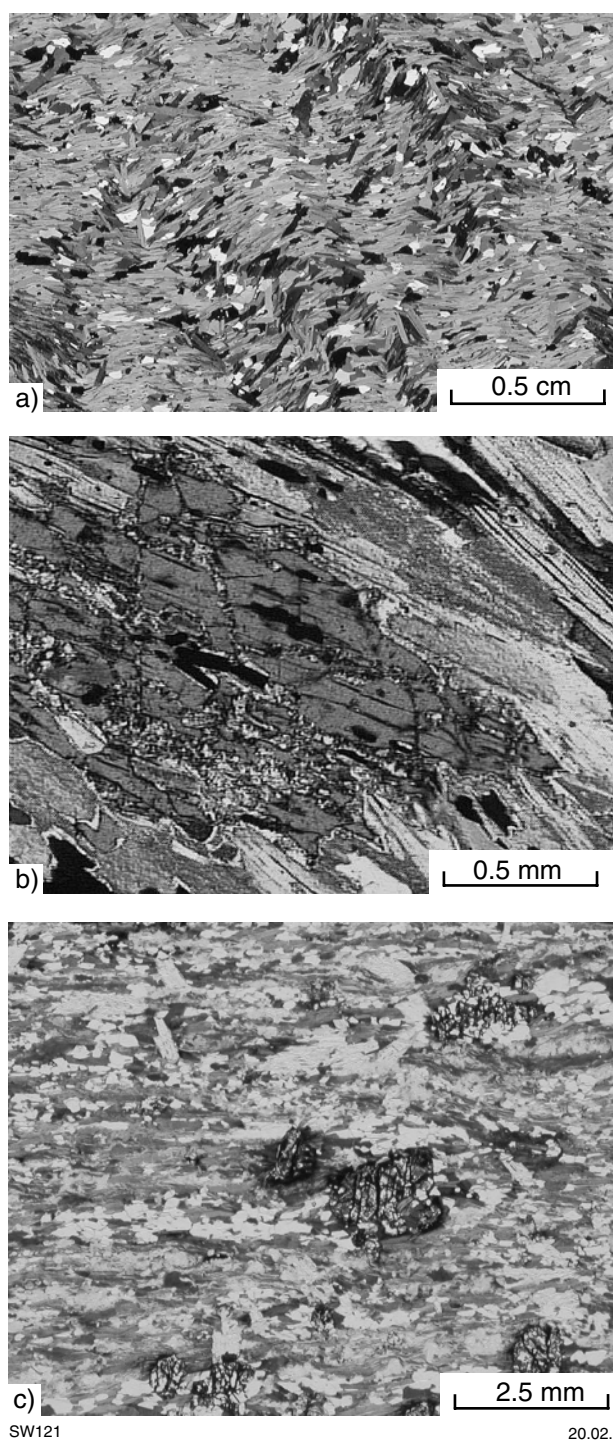


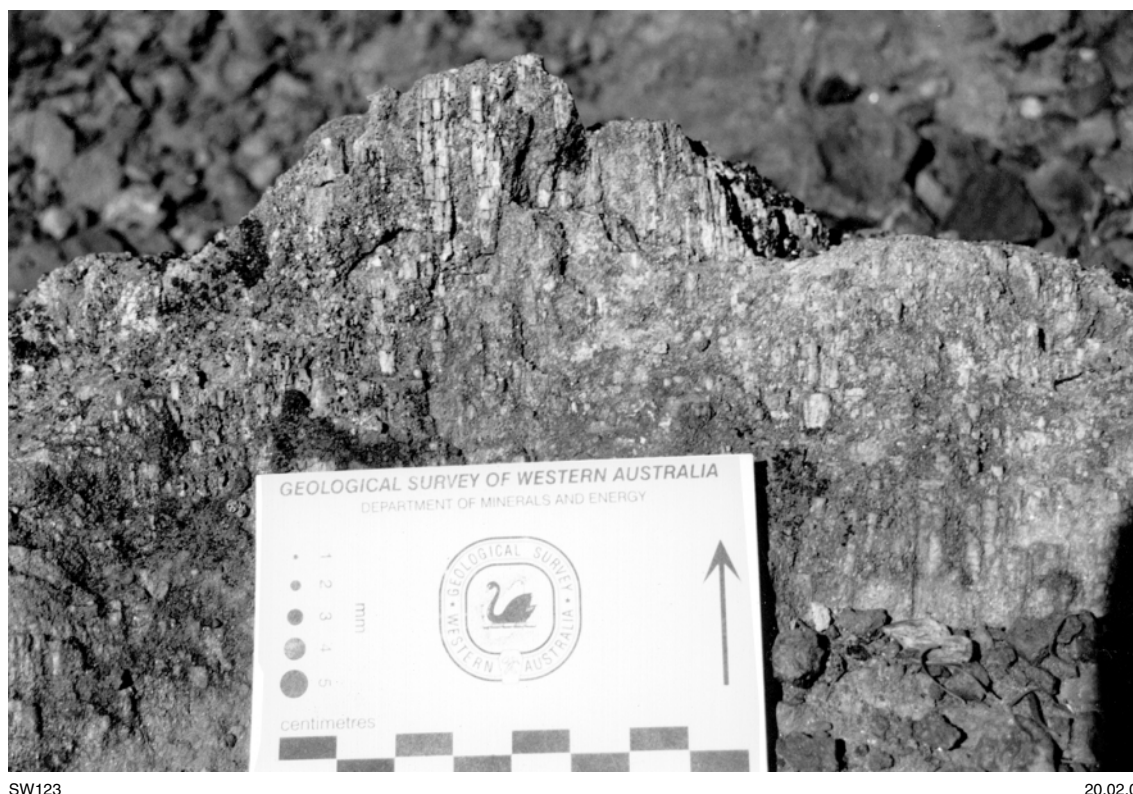
Figure 8. Metamorphic map of the greenstone belts on LAKE GILES. Thin-section localities are shown as dots, and the timing relationships between porphyroblast growth and foliation are also indicated. Metamorphic terminology follows Ahmat (1986)



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Figure 9. Photomicrographs of pelitic schist from the South Elvire belt (MGA 763400E 6722500N):
 a) S₁ muscovite foliation crenulated by D₂;
 b) sillimanite porphyroblast overprinting muscovite foliation; c) garnet overprinting biotite foliation



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Figure 10. Sillimanite porphyroblasts have grown parallel to the D_2 – D_3 fold axis; scale bar shown is in centimetres

Isolated outcrops of calcrete (*Rk*) on LAKE GILES are commonly associated with deeply weathered mafic or ultramafic rocks and ferruginous duricrust. Occurrences typically form numerous small patches of light-grey calcrete nodules amongst colluvium and sheetwash. Deeply weathered ultramafic rocks also develop hard, siliceous caprocks (*Rzu*). These are commonly massive and light brown; they may also contain relict igneous cumulate or spinifex textures.

Depositional units (*C*, *Cf*, *Cgp_g*, *Clc_i*, *Cq*, *W*, *A*, *L_i*, *L1_d*, *L_m*, *L2_d*, *S*, *Sl*)

The depositional regime on LAKE GILES is dominated by the Lake Barlee and Lake Giles playa-lake systems. Colluvium and sheetwash merge into broad alluvial channels, which connect to the lake margins.

Colluvium (*C*) is found on sloping or undulating ground adjacent to greenstone outcrop, and consists of poorly sorted sand, silt, and gravel from mixed erosional sources. Colluvium has been subdivided where it is dominated by a particular source. This includes dominantly ferruginous material derived from reworked duricrust (*Cf*). Quartzofeldspathic colluvium was derived from an adjacent granitoid source (*Cgp_g*), while highly ferruginous colluvium (*Clc_i*) includes pebble- and boulder-sized talus from adjacent BIF ridges. Local colluvium from large quartz veins (*Cq*) also contains pebble- and boulder-sized quartz talus.

Sheetwash units (*W*) consist of well-sorted sand, silt, and clay material. They are gradational between colluvial and alluvial units and are found on floodplains to very gentle slopes. Alluvium (*A*) contains sand, silt, and gravel from various sources. It is confined to distinct channels (marked as watercourses) and floodplains, and has been distinguished from sheetwash by airphoto and Landsat image interpretation.

Lacustrine deposits dominate the central region of LAKE GILES, and represent a large-scale palaeodrainage watershed (Hocking and Cockbain, 1990). Lake-surface deposits (*L_i*) consist of monotonous, flat expanses of dark mud and clay covered by a thin veneer of crystalline halite, carbonate, and gypsum. Sand dunes within playa lakes consist of sand and minor detrital gypsum, and are divided into active (*L1_d*) and stabilized (*L2_d*) dunes. Active dunes are barren or have very minor vegetation cover, whereas stabilized dunes are colonized by saltbush and eucalypt trees. The flat to undulating margins of the playa lakes contain a mixture of dunes, evaporite, and alluvial deposits (*L_m*).

Areas of consistently thick sand deposits (*S*) have been recognized on LAKE GILES. They consist of well-sorted quartzofeldspathic sand with minor pisolitic material (*Sl*). Their dominant association with duricrust units over granitoid rocks suggests they may have been deposited roughly in situ, although some sandplain over greenstones (e.g. MGA 775000E 6710600N) is clearly transported.

Economic geology

Although there is little recorded mineral production on LAKE GILES, there has been significant surface and near-surface gold and nickel exploration based mostly on soil sampling, and rotary air blast (RAB) and reverse circulation (RC) drilling. Exploration for gold and nickel is continuing, with all greenstone belts on LAKE GILES covered by mineral tenements.

Gold

The only recorded mineral production from LAKE GILES is 0.565 kg of gold from the Sunrize prospect (MGA 742450 6707465) in the Evanston belt (Townsend et al., 2000). However, there has been no documentation of this prospect.

A shallow shaft has been sunk on the granite–greenstone contact at Rainy Rocks in the Evanston belt (MGA 748800E 6715100N), and historical gold prospects to the south of this locality (MGA 748600E 6713700N) are found in folded metagabbro containing epidote and sulfide. However, no production has been recorded from these workings (Matheson and Miles, 1947).

Systematic exploration for gold in recent years has focused on structurally controlled quartz veining associated with carbonate–sulfide alteration. Favourable structures include major shear zones (especially the Evanston Shear Zone), major folds (especially large-scale synclines in the Mount Manning and Yerilgee belts), fault jogs, and fault intersections. Banded iron-formation has been the most targeted rock type, especially when in contact with chlorite–talc schist. Details of recent gold exploration activity can be found in the GSWA's WAMEX database.

Iron oxides

The prominent BIF ridges in the Mount Manning Range were explored for iron ore mineralization in the early 1960s (Western Mining Corporation Ltd, 1965). The potential for 20 320 t of iron ore was estimated in well-bedded massive hematite with minor magnetite. Samples at this prospect returned analyses of 60% iron.

Nickel

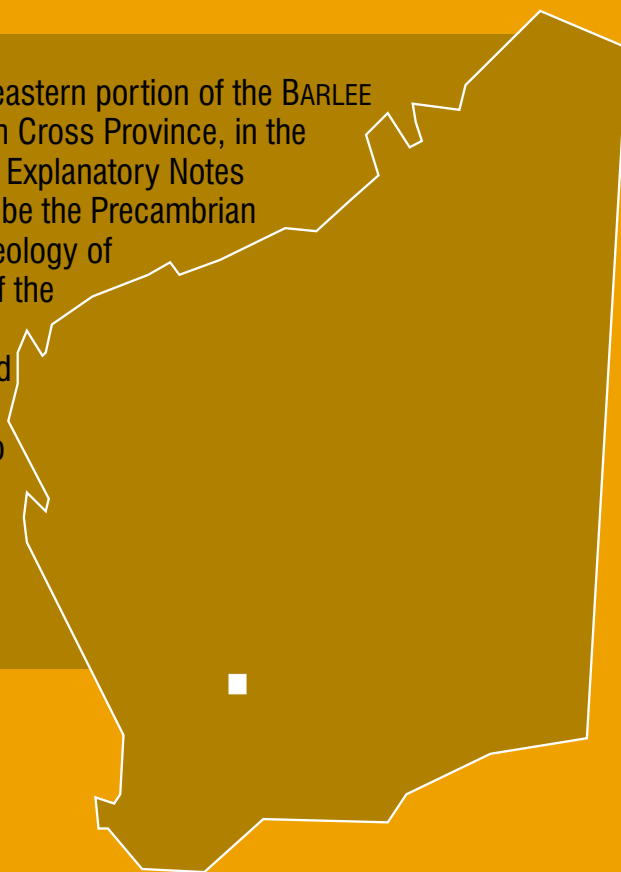
Nickel–copper exploration flourished in a brief but intense period between 1968 and 1972. Ultramafic units, especially in the Yerilgee and Mount Manning belts, were targeted for nickel–copper–cobalt–chromium mineralization. The most widely used exploration methods included ground and aerial magnetic surveys, transient electromagnetic surveys, soil sampling, and costeaning, with follow-up percussion and diamond drilling. Areas of sulfide alteration, including pyroxenites, peridotites, and ultramafic–BIF contacts, were favoured exploration targets. There have been no economic nickel discoveries on LAKE GILES to date, although some anomalous nickel and chromium results have yet to be followed up. Details of this exploration can be found through the GSWA's WAMEX database.

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The LAKE GILES 1:100 000 sheet covers the southeastern portion of the BARLEE 1:250 000 sheet in the central part of the Southern Cross Province, in the central part of the Archaean Yilgarn Craton. These Explanatory Notes complement the 1:100 000-scale map, and describe the Precambrian rock types, and the structural and metamorphic geology of the granite–greenstone terrain. The composition of the greenstone belts in the sheet area, and the deformation history and its relationship to granitoid intrusion are discussed. Recorded mineralization and the extensive Cainozoic regolith cover are also described.



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